Logistics Reduction: RFID Enabled Autonomous Logistics Management (REALM) (LR-REALM)

Active Technology Project (2015 - 2023)

Project Introduction

The Advanced Exploration Systems (AES) Logistics Reduction (LR) project Radio-frequency identification (RFID) Enabled Autonomous Logistics Management (REALM) task focuses on automated localization and inventory of all physical assets pertaining to, or within, a vehicle utilizing RFID technologies. REALM technology can provide detailed data to enable autonomous operations such as automated crew procedure generation and robotic interaction with logistics and deep space habitats; this is especially of value where communication delays with Earth drive the need for self-reliance. The REALM project is conducting a series of ISS technology demonstrations. The first ISS demonstration, REALM-1, started in February 2017 and was completed at the end of FY19 when it was transitioned to the ISS Program for sustaining operations. The second ISS demonstration, REALM-2, was commissioned in late 2021 and will continue through 2022. The third demonstration, REALM-3, is currently in development and is expected to launch in June of 2022.

The problem of locating all mission items within and around a vehicle is complicated by many factors, including the desire to rely only on passive tags, restrictions on RF transmit power, layered storage of logistics, the challenging RF scattering environment of vehicles, and metallic storage enclosures. To address these complex problems, associated RFID technologies are partitioned into three classes:

Dense Zone technologies

Sparse Zone technologies

Complex Event Processing

Dense Zone technologies pertain to regions of high stowage densities where sufficient signal penetration from external antennas is unlikely. Sparse zone technologies address all areas exclusive of the dense zones, including the open areas of a habitat module. These technologies include fixed-zone readers, steered-beam antenna readers, and mobile readers such as robotic elements, crew-held readers, or crew-worn readers. With both dense and sparse zones, guaranteed real-time, on-demand reads may not be possible, so "smart" applications, e.g., Complex Event Processing (CEP), are required to infer item locations based on context from the sparse and dense zone technologies.

Mission details might drive a specific combination of one or more of these three technologies. Therefore, in addition to maturing these individual technology areas, the LR REALM team will learn which combinations of technologies are best suited for specific missions. For example, dense zone technologies can be made highly accurate but typically entail greater mass compared to sparse zone technologies. Sparse zone technologies typically cover greater volume per reader, but are more apt to miss tags because the radiated power density at the tag is typically lower in comparison. The

REALM-1 EMBER Reader

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operational intelligence provided by CEP can likely be traded for the size, weight, and power associated with dense and sparse zone technologies, but the extent, and specific implementation, remain as knowledge gaps to be addressed by this effort.

The REALM task is divided into five sub-technology projects: REALM-1, -2, -3, -6DoF, and REALM-RFID Sensing.

REALM-1

REALM-1 infrastructure was developed and evaluated on ISS, with RFID open-air readers and antennas deployed in ISS Node 1, U.S. Laboratory, and Node 2. A ground-based CEP center receives data from the ISS open-air readers and provides operational intelligence that infers item locations. The REALM-1 core system was considered sufficiently matured in FY19 and was transitioned to an operational ISS system midway between FY19 and mid-FY20, so that ISS became responsible for sustaining engineering of flight and ground REALM-1 assets.

With the REALM-1 on-orbit system having been fully transitioned from Payload status to System on ISS, the CEP/machine learning approaches remain a central focus going forward. This task serves four primary purposes. First, the largest improvements to date in CEP localization occurred with machine learning classifier approaches in FY20. Trials on two different machine learning (ML) algorithms continued in FY21 and FY22 to further extract value from this technology as deeper knowledge of both the ML tools and the problem space evolve. Second, new context from REALM-2 and REALM-3 will be folded into the CEP, a critical step in understanding the value, impacts, and interdependencies of fixed reader systems, mobile reader systems, and stowage reader systems in ALM. Third, the REALM Analog at JSC, which is a horizontal cylindrical habitat test bed similar to HALO in dimensions, will be employed to understand the impacts of habitat shell geometry and interior stowage regions and furnishings on localization accuracy. Fourth and finally, the REALM Analog will be used to better understand and improve the ISS CEP performance, given the ability to better control experiments with an increased truth data size.

Other CEP work in FY22 includes continuation of tag motion inferences and mining of crew procedures. Identifying tag motion enables other capabilities such as determining items that are being transferred to a visiting vehicle – either as intended or otherwise. Mining of ISS databases allows for additional CEP context in estimating item locations and enables auto-alerts when REALM detects that logistics required in next-day's procedures are not where IMS indicates. ISS database mining efforts were initiated in late FY20 and initial, FY21 results provided corroboration with that ISS database, or alerted when

Organizational Responsibility

Responsible Mission Directorate:

Exploration Systems Development Mission Directorate (ESDMD)

Lead Center / Facility:

Johnson Space Center (JSC)

Responsible Program:

Exploration Capabilities

Project Management

Program Director:
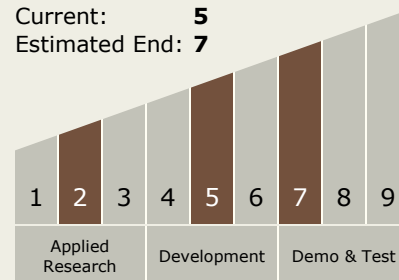
Christopher L Moore

Project Managers:

Patrick W Fink
Andrew W Chu
Melissa K Mckinley

Principal Investigator:

Patrick W Fink

Technology Maturity (TRL)

Start: **2**
Current: **5**
Estimated End: **7**

1	2	3	4	5	6	7	8	9
Applied Research			Development			Demo & Test		

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REALM detected significant deviations.

Other ISS experiments at various stages of maturity are being developed with anticipated use of the REALM-1 infrastructure. These include the REALM-2 and REALM-3 systems, described in more detail below, and the 6-Degrees of Freedom (DoF) Wireless Hybrid Identification and Sensing Platform for Equipment Recovery (WHISPER).

The REALM-1 system is baselined for the Gateway Program's HALO and iHAB elements. Up to 8 REALM-1 antennas may be placed in HALO, with primary functionality providing assurance of cargo transfer between the Logistics Module and the Human Lander System. The system will also be capable of tracking cargo to and from the Orion vehicle. REALM instrumentation in other Artemis and Gateway elements is still under consideration.

REALM-2

REALM-2 (aka "Recon") is an AES LR RFID interrogator payload on the Space Technology Mission Directorate (STMD) Next Generation Free-Flyer (NGFF), aka "Astrobee." REALM-2, located inside the ISS, is capable of conducting inventory missions, or audits, as well as search missions to locate lost items and homing missions to pinpoint item locations. Another capability afforded by REALM-2, referred to as "CEP Context," is the CEP integration of data received over the four REALM-2 antennas with the REALM-1 data to improve tag localization accuracy. The REALM-2 flight system was delivered for a November FY20 launch. Crew installation of REALM-2 was completed in January 2021 with commissioning and checkout completed and further experiments occurring in FY21 and FY22.

Two REALM-2 science missions were executed in FY21. In Science-1, Astrobee was perched inside the hatch of the Permanent Multi-Purpose Module (PMM), giving REALM-2 a vantage point with visibility into the largest logistics stowage volume on ISS. The number of unique tags read, as a fraction of all tags in PMM (as reported by the ISS database), jumped from just under 3% from REALM-1, only, to 65% by REALM-2. In addition, several stowage tracking anomalies were uncovered by REALM-2 during this three-hour mission. In a Science-2 mission, the homing functionality was further tested, and code errors were discovered in the pitch and yaw commands, attributed to inverted test article orientation required for ground testing. In FY22, the code error was corrected and confirmed in Science-3 mission, in which REALM-2 guided Astrobee on several successful homing runs. In Science-4, Astrobee was perched in various positions and translated in JPM in order to assess RFID inventory capture effectiveness in perched versus mobile scenarios. A Science-5 mission is being planned for September 2022 in which Astrobee monitors for crew cargo translations in an attempt to emulate Gateway

Technology Areas

Primary:

- TX07 Exploration Destination Systems
  └ TX07.2 Mission Infrastructure, Sustainability, and Supportability
     └ TX07.2.1 Logistics Management

Target Destinations
Earth, The Moon, Mars

Supported Mission Type
Planned Mission (Pull)

logistics transfers.

REALM-3

In general terms, REALM-3 is a dense zone reader enclosure in the form of "smart" drawers, cargo bags, and work bags, where a large number of RFID-tagged items occupy a relatively small volume. Open reader systems such as REALM-1 do not typically handle regions such as this with high read accuracy, either due to the high tag density or metallic racks/enclosures. Studies with REALM-1 indicate that the real time RFID audit accuracy in NOD1 ranges from 72-76% of all tagged items there, as reported by the ISS database; REALM-3 technology can significantly improve total read accuracy.

In FY21, flight development of REALM-3 under the ISS Payload named "RFID-Sensing" began with launch planned in May 2022. "RFID-Sensing" comprises Smart Stow and the Drawer Monitor System. Both of these technologies were conceived to overcome the aforementioned challenges with dense packing and/or items with metal or liquid content. The Smart Stow system comprises RFID signals routed to antennas embedded in a stowage enclosure. While highly effective, Smart Stow requires too much instrumentation to replicate throughout all racks on a vehicle. The Drawer Monitor System complements Smart Stow and entails much lower mass, so it is more amenable to wide proliferation throughout a vehicle, with Smart Stow allotted to stowage enclosures of frequent usage. The Drawer Monitor System is based on RFID sensor technology and hence is addressed in that section below.

In FY20, a new approach was initiated to increase the RFID coverage area with significantly lower mass than would be required by simply adding more readers and antennas. This approach, termed "HYDRA" (HYper-Distributed RFID Antenna), is based on switched multiplexing of one or more of the reader RFID ports. The increased proliferation of the RFID signal is anticipated to allow blurring of the "dense" and "sparse" zones, as a single reader could support both using HYDRA. This concept advanced from TRL 3 to TRL 6 by the end of FY21, and is integrated within the Smart Stow textile rack insert. Smart Stow will be installed by the crew in the NOD1S4 zero-gravity stowage rack. A reader instance, of the same type used by REALM-1, will be dedicated to Smart Stow, and will be scheduled on intervals of nominally 15 minutes to successively interrogate each of four quadrants in NOD1S4. Each quadrant will contain several HYDRA nodes and six antennas. Although this instrumentation is much denser than is anticipated in future vehicles, the intent is to fully test a HYDRA system in ISS that would eventually be distributed over a significantly larger vehicle volume.
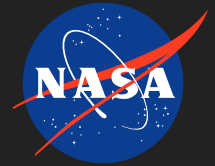
REALM-6DoF (6 Degrees of Freedom)

The REALM team is collaborating with Advanced Systems and Technologies Inc. (AS&T) to advance an ultra-precise WHISPER (Wireless Hybrid Identification and Sensing Platform for Equipment Recovery) RFID tracking system that will be compatible with the REALM-1 infrastructure. The AS&T WHISPER technology is being developed under a Small Business Innovative Research (SBIR) award. Their new tag and tracking system enhancement permits theoretical tracking accuracies at centimetric and millimetric levels as well as orientation tracking. In FY20 and FY21, AS&T developed a reduced size infrared projector, referred to as the "Intermediate WHISPER Projector" (IWP). Although not as small as the eventual target, its 3"x3"x3" size renders it suitable for an ISS technology demonstration experiment.

In Q4 of FY21, AS&T performed two virtual demonstrations of the WHISPER technology, with highlights including tracking of a human subject, a translated articulated robotic appendage, and a helicopter drone. At the end of FY21,

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AS&T delivered to NASA six IWP projectors. In FY22, AS&T will set up and calibrate the IWP projectors at JSC, with the goal of providing demonstrations and evaluations for prospective end user applications, including robotic manipulation of logistics and resolution of the Human Research Program (HRP) knowledge gap regarding how the crew utilizes habitat volume.

REALM-RFID Sensing

The REALM team is leveraging RFID integrated circuits (ICs) that offer serial interfaces in addition to the more conventional over-the-air radiated interface to an RFID tag. The serial interface permits attachment of a microcontroller and low-power sensors such that the resulting tag is capable of returning sensor data in addition to the typical code that uniquely identifies the tag. In FY20, the REALM team began applying this technology in the form of RFID tags that monitor door motion, and in FY21 began development of a flight Drawer Monitor System (DMS).

In the DMS concept of operation, the REALM-1 system will read tagged items until they are placed inside of a drawer and cease to be "seen." Data pulled from the door-mounted DMS tags will relay door motion events and the time of those events. The CEP system will use that sensor data from the door tag, in addition to the data read from the conventional RFID tag on the item, and infer whether the tag has been moved into a particular drawer.

In FY22, the REALM team completed fabrication, assembly, and certification of the flight Drawer Monitor System tags.   The team will launch the DMS tags as part of the REALM-3 payload in September 2022.
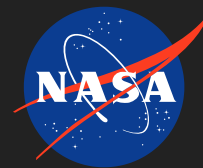
Anticipated Benefits

The REALM technology has the potential to dramatically reduce crew time expended on general inventory management and searching for lost items. The REALM-1 ISS technology demonstration has had several successful finds of lost items that provide the initial validation of crew time savings. Moreover, assured localization of assets can enable heterogeneous packing to optimize volume efficiency rather than crew-time efficiency.
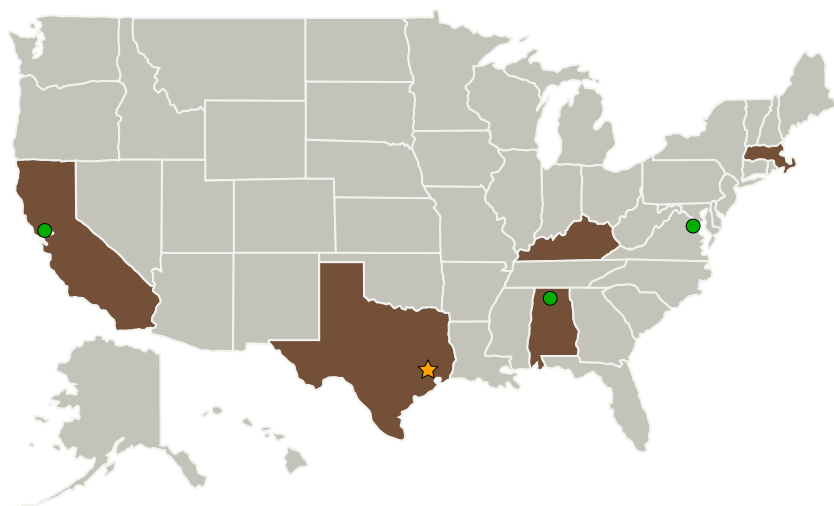
Currently, foam is used to package items less densely in order to facilitate crew access to items. REALM can allow rapid location of items in densely packed Cargo Transfer Bags (CTBs) that could reduce foam usage in logistics packaging by up to 50%. The reduction in foam volume will provide increased habitation volume in logistics vehicles and deep space habitats. For robotic precursor missions, REALM technology can enable machine interaction with logistics, including packing and assembly functions in advance of crew arrival. In particular, the REALM-6DoF in combination with REALM-1, has a host of other potential applications, including that of robotic navigation aid. It thus has the potential to satisfy the ALM technology roadmap gap of a so-called 6-degree-of-freedom tag system.

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Primary U.S. Work Locations and Key Partners

Organizations Performing Work	Role	Type	Location
⭐Johnson Space Center(JSC)	Lead Organization	NASA Center	Houston, Texas
🟢Ames Research Center(ARC)	Supporting Organization	NASA Center	Moffett Field, California
🟢Marshall Space Flight Center(MSFC)	Supporting Organization	NASA Center	Huntsville, Alabama
🟢NASA Headquarters(HQ)	Supporting Organization	NASA Center	Washington, District of Columbia
University of Kentucky	Supporting Organization	Academia	Lexington, Kentucky
University of Massachusetts-Amherst(UMASS)	Supporting Organization	Academia	Amherst, Massachusetts

Co-Funding Partners	Type	Location
Altius Space Machines, Inc.	Industry	Broomfield, Colorado
Baylor College of Medicine	Academia	Houston, Texas

Primary U.S. Work Locations	
Alabama	California
District of Columbia	Kentucky
Massachusetts	Texas

Images
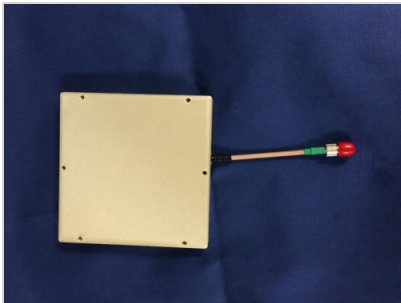
REALM-1 Flight Antenna
REALM-1 flight antenna that was developed in-house. ~80% smaller than COTS antenna and maintains similar performance.
(https://techport.nasa.gov/image/143609)

REALM-1 reader unit with fan assembly in flight-like housing
REALM-1 EMBER Reader
(https://techport.nasa.gov/image/143608)

Links

Conference paper on Autonomous Logistics Managment Systems for Exploration Missions
(https://arc.aiaa.org/doi/10.2514/6.2017-5256)

ISS REALM-1 Experiment Description
(https://www.nasa.gov/mission_pages/station/research/experiments/2137.html)

REALM Technology Overview Video (youtube)
(https://www.youtube.com/watch?v=0bcWA-HnSSY)